The option of implementing an RF deflector in the NGLS Spreader

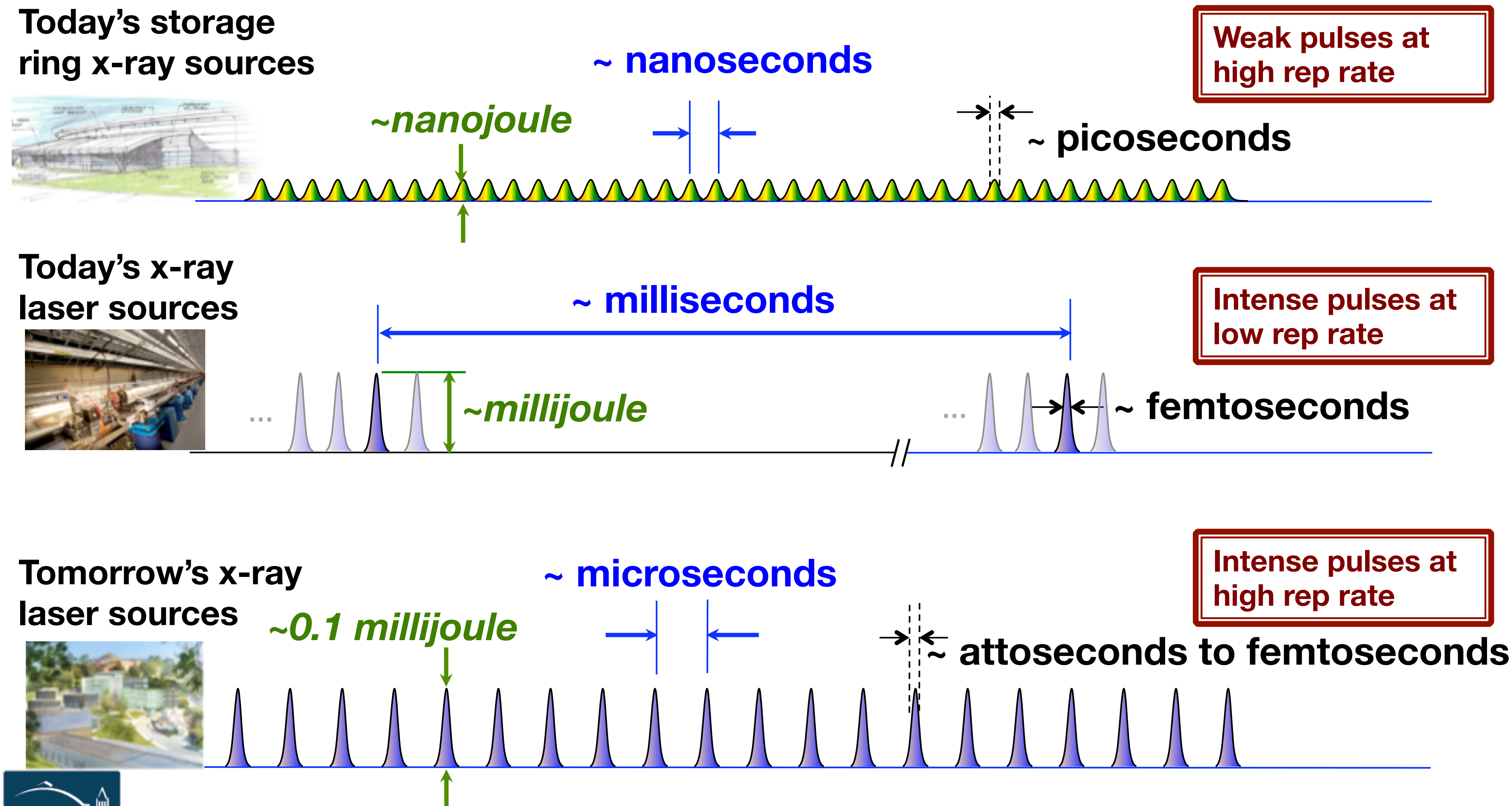
A. Ratti, M. Placidi

and the NGLS design team

19 July 2012

NGLS Motivation

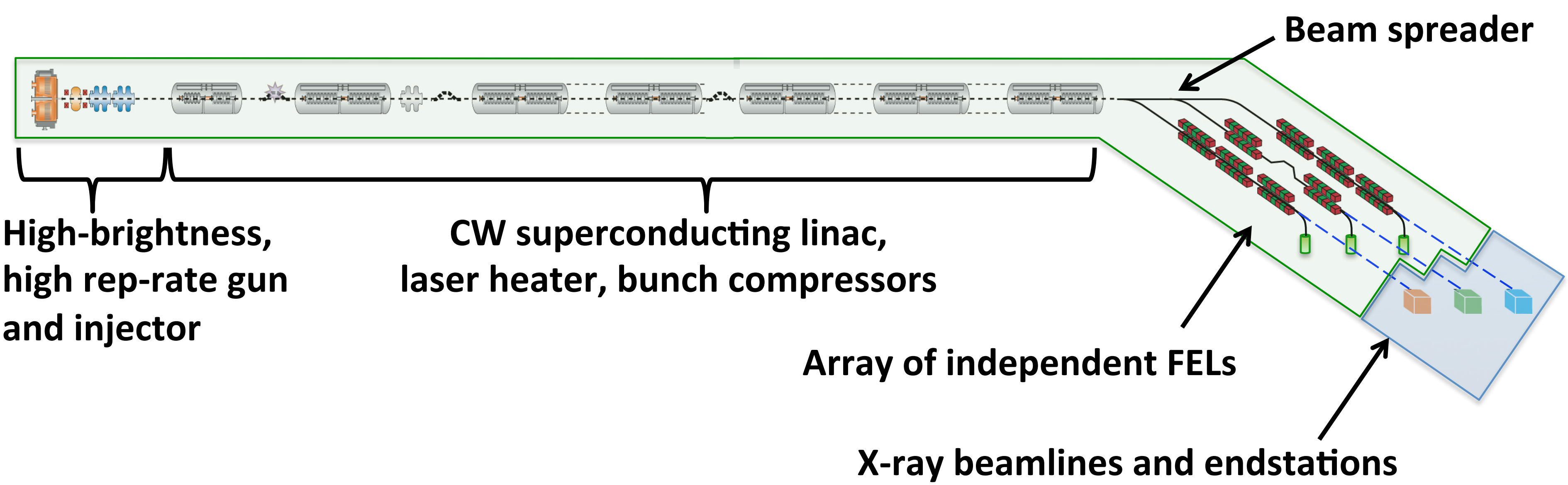
Coherent X-rays with high repetition rate, unprecedented average brightness, and ultrafast pulses



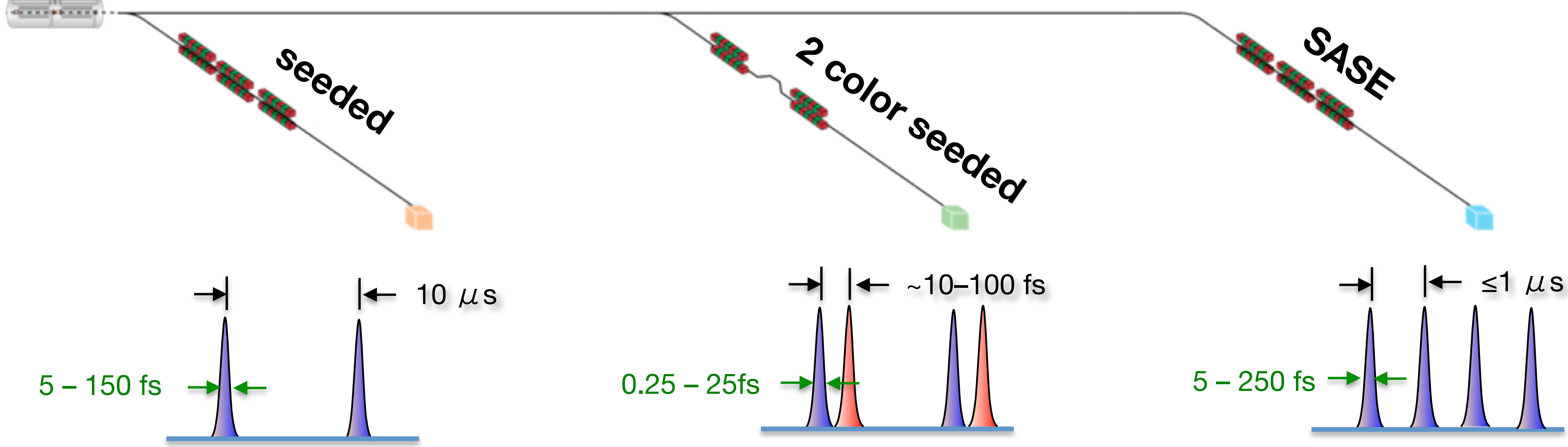
NGLS Approach

NGLS next generation light source

High average power electron beam distributed to an array of FELs from high rep-rate injector and CW SCRF linac



Three initial FEL beamlines to span the science case



- Up to 100 kHz
- High resolution
- ~Time-bandwidth limited
- 10^{11} – 10^{12} photons/pulse
- 10^{-3} – 5×10^{-5} $\Delta\omega/\omega$

- *High-resolution spectroscopy*
- *Diffractive imaging (with harmonics)*

- Up to 100 kHz
- Ultra-fast
- 250 as pulses
- Two color
- 10^8 ph/pulse

- *Multidimensional X-ray spectroscopy*

- Highest rep rate, MHz and greater
- High flux
- 10^{11} - 10^{12} photon/pulse
- 100 W

- *Diffractive imaging (at highest rate)*
- *Photon correlation spectroscopy*

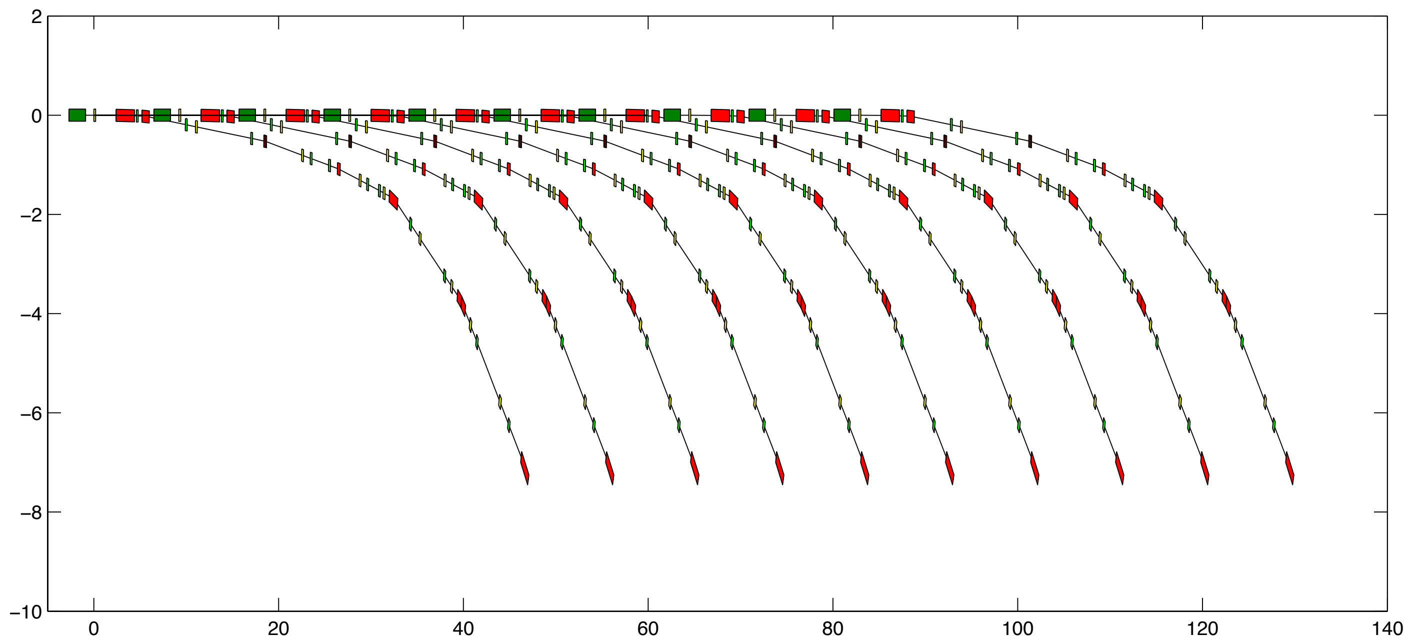
Spreader Baseline: Footprint

C. Sun

Baseline - Take-Off DOFO cell, **9.2m** length, **45°** phase advance

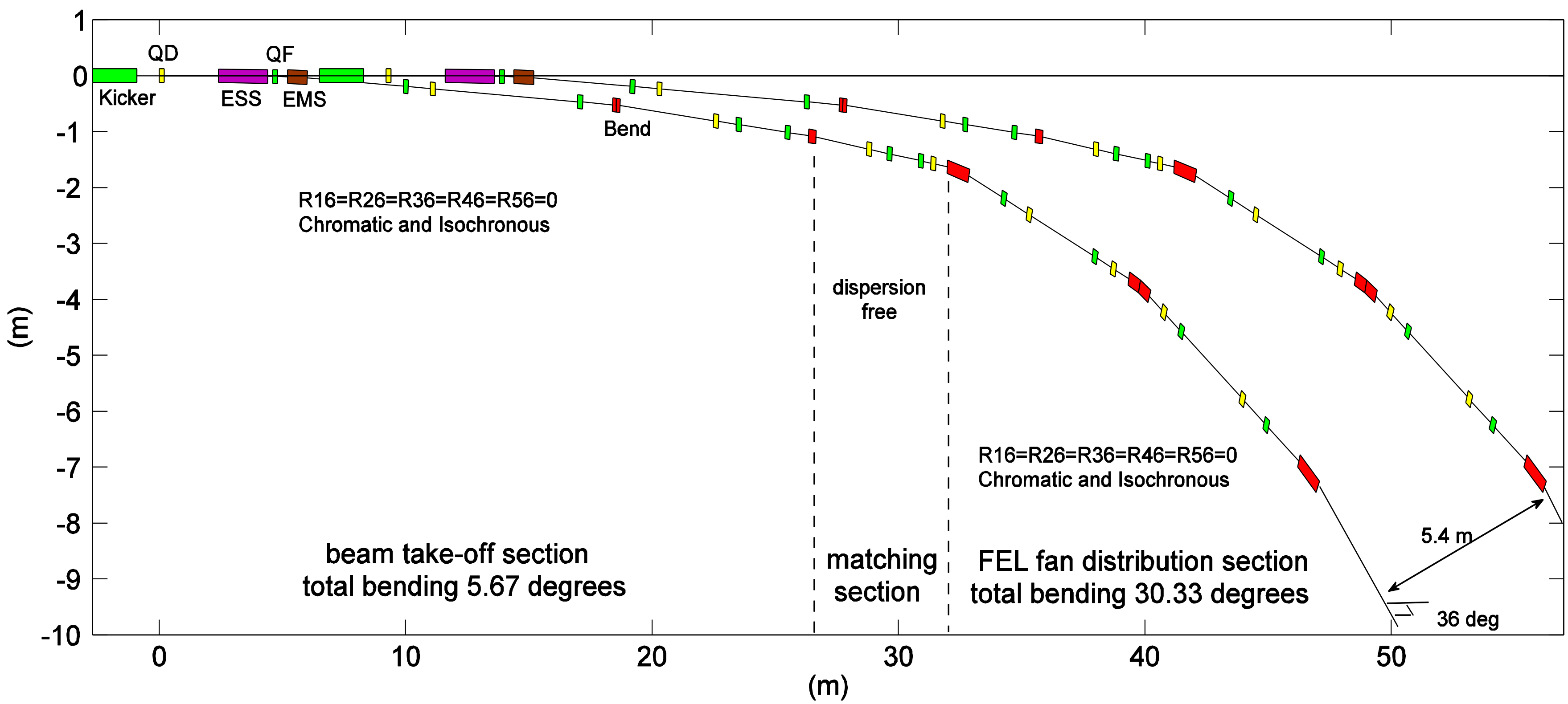
ARCs: Two separate double-bend achromats, **36° total deflection**

Total footprint: **~135 x 7.8m²**



Baseline: Single BeamLines

C. Sun



EM Kicker Requirements

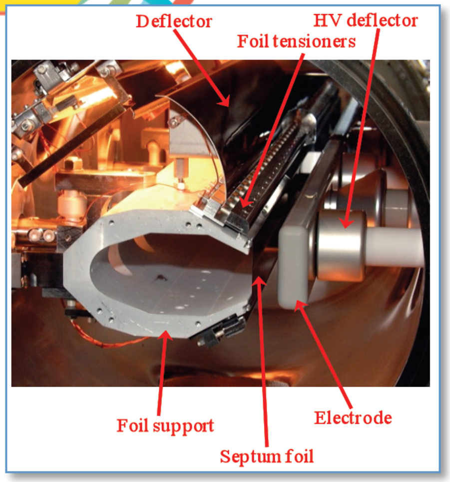
Parameter	Symbol	Unit	Value
Beam Energy	E	GeV	2.6
Bend Angle	θ_k	mrad	0.7
Kicker Length	L_k	m	1.8
Magnetic Strength	B_k	G	33.7
Magnet Aperture	-	mm	17.0 x 17.0
Magnet Length	-	m	0.12
# of Magnets	-	-	15
Integrated B Field Rise/ Fall Time	-	ns	50
Repetition Frequency	-	kHz	100
Pulse to Pulse Stability	-	-	4×10^{-4}
Interpulse Ripple	-	-	4×10^{-4}
Magnet Current	I_k	A	45.59
MOSFET Voltage		V	<700
Switch Rise/Fall Time	-	ns	<10
Magnet Fill Time	-	ns	<30
Average Power (System)	-	kW	1.91
Chamber Resistance	-	mΩ/sq	50
Chamber Dissipation (@ 1-nC/bunch)	-	W/m	800.0

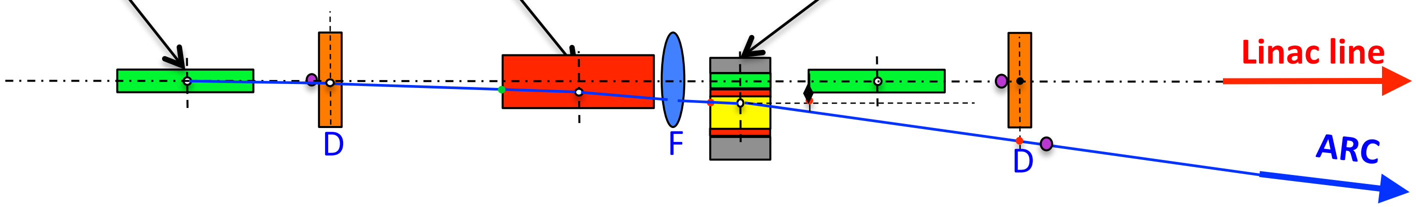
Kicker Spreader Overview

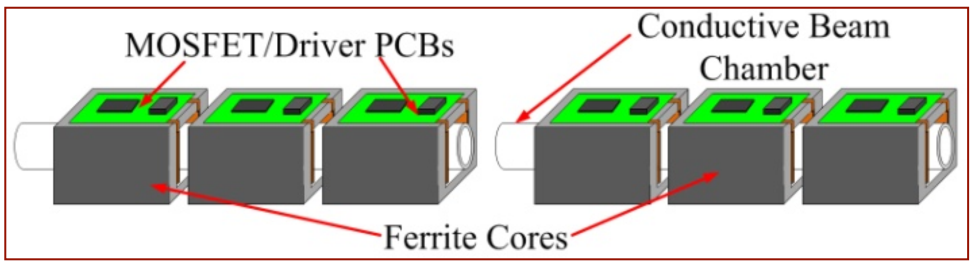
Kicker
1.8 m,
0.7 mrad

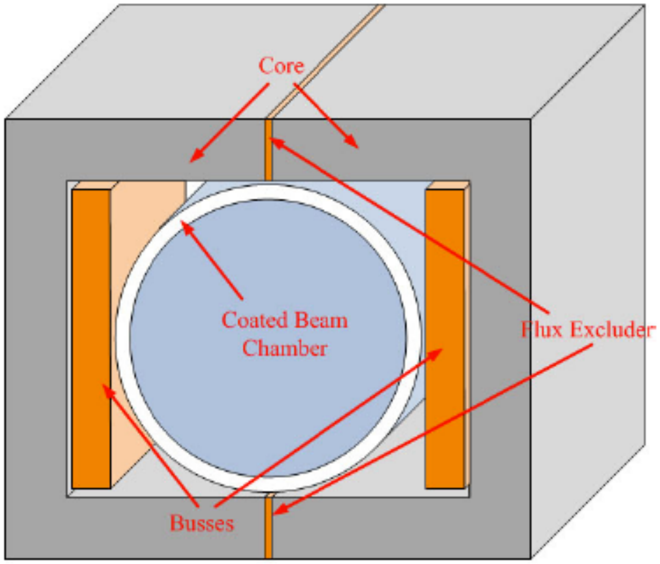
Electrostatic septum
2.0 m,
7.7 mrad

Magnetic septum
0.8 m,
33 mrad

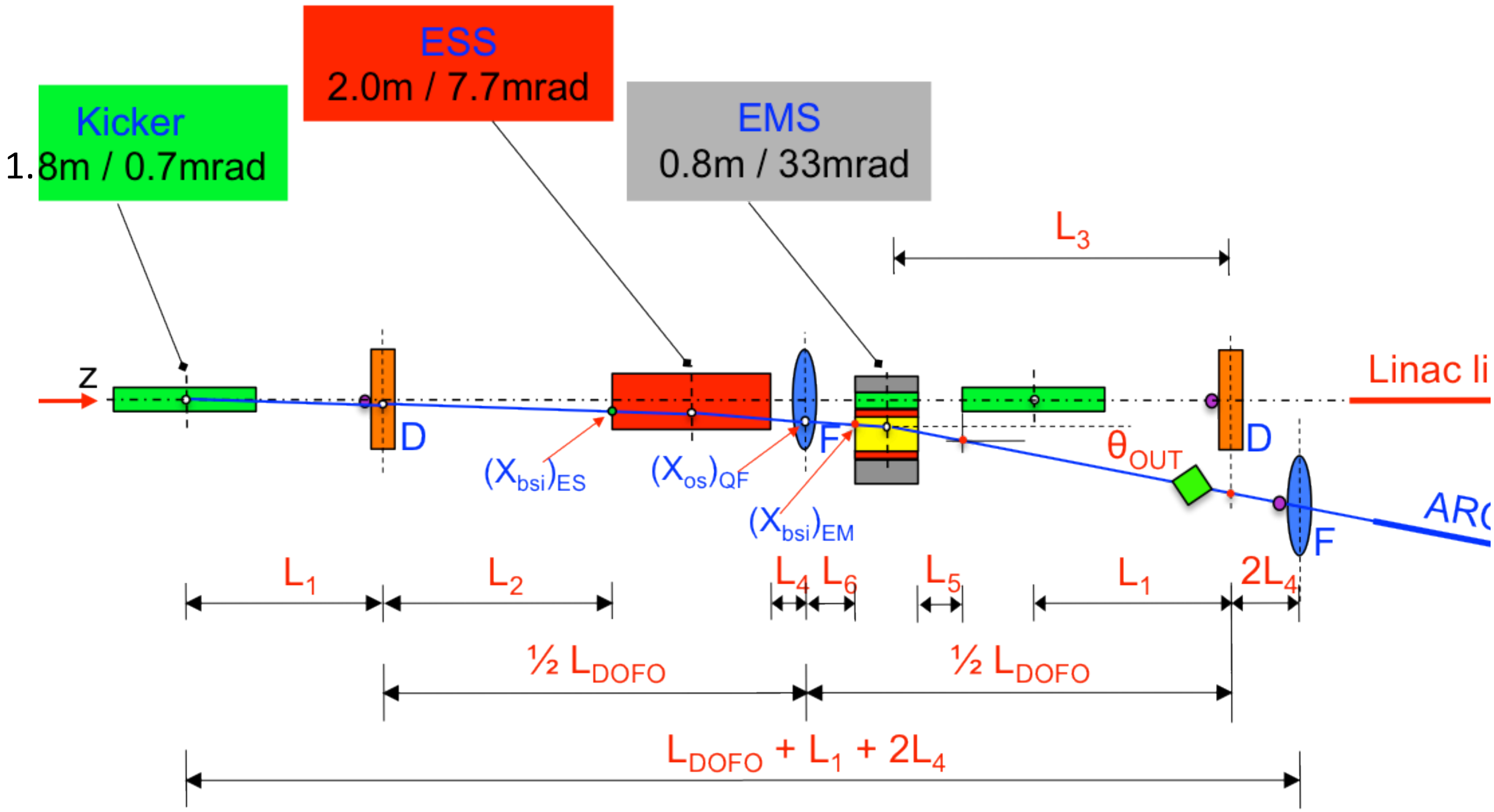








Spreader Take-off baseline design



Challenges for baseline approach

- Limited pulser rep rate – 100 ->few kHz
- High pulser stability and repeatibility requirements – few 10^{-4}
- Challenging Electro Static Septum Design
  - Thin electrode exposed to synchrotron radiation from deflected bunches can cause foil local heating and electron photo emission

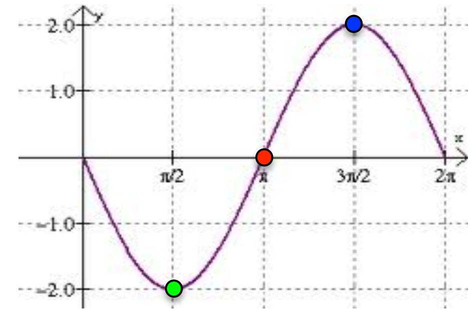
DC Constraints

- Alternative scheme aiming at replacing Kicker + ESS with DCs
- Footprint comparable to (smaller than) present
- Should not reduce beam separation at EMS
- Should not exceed offsets in QF next to EMS
- Include room for FODO lattices
- Allow for beam lines separation as required

Scenarios

DC Scenarios depend on Residual spatial chirp at zero-Xing

- **TOLERABLE : 3-WAY SEPARATION**
  - **How many beamlines**
  - **How many RF Frequencies**
  - **DC Septum Options: T-EMS (T-LS)**



Emittance diluition from Paul Emma's TN-20:

P. Emma, NGLS Tech Note-0020 / 06.16.2012

dependence on $\lambda^{-1/2}$ HELPS!

$$\frac{\Delta\varepsilon}{\varepsilon_0} \approx \sqrt{1 + \left(\frac{2\pi x_0' \sigma_z}{\lambda}\right)^2 \frac{\beta\gamma}{\varepsilon_N}} - 1 < 10\%$$

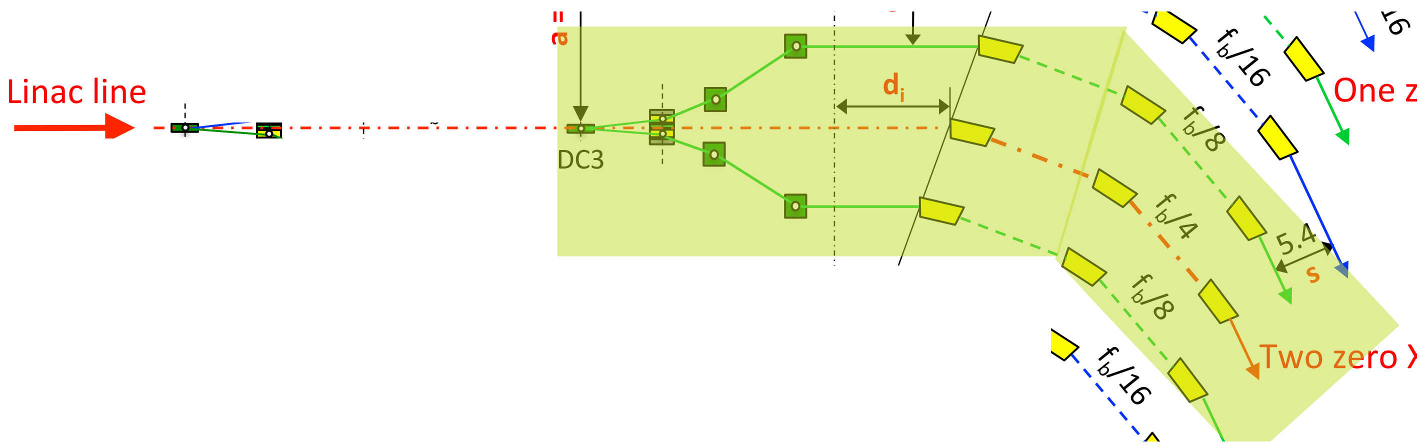
f_{RF}/f_{LINAC}	f_{RF} /MHz	λ_{RF} / mm	$\Delta\varepsilon/\varepsilon_0$
1/2	650	462	14.6%
1/3	433	693	6.7
1/4	325	923	3.9

Investigate DC schemes including un-deflected pass at zero-crossing

Comments

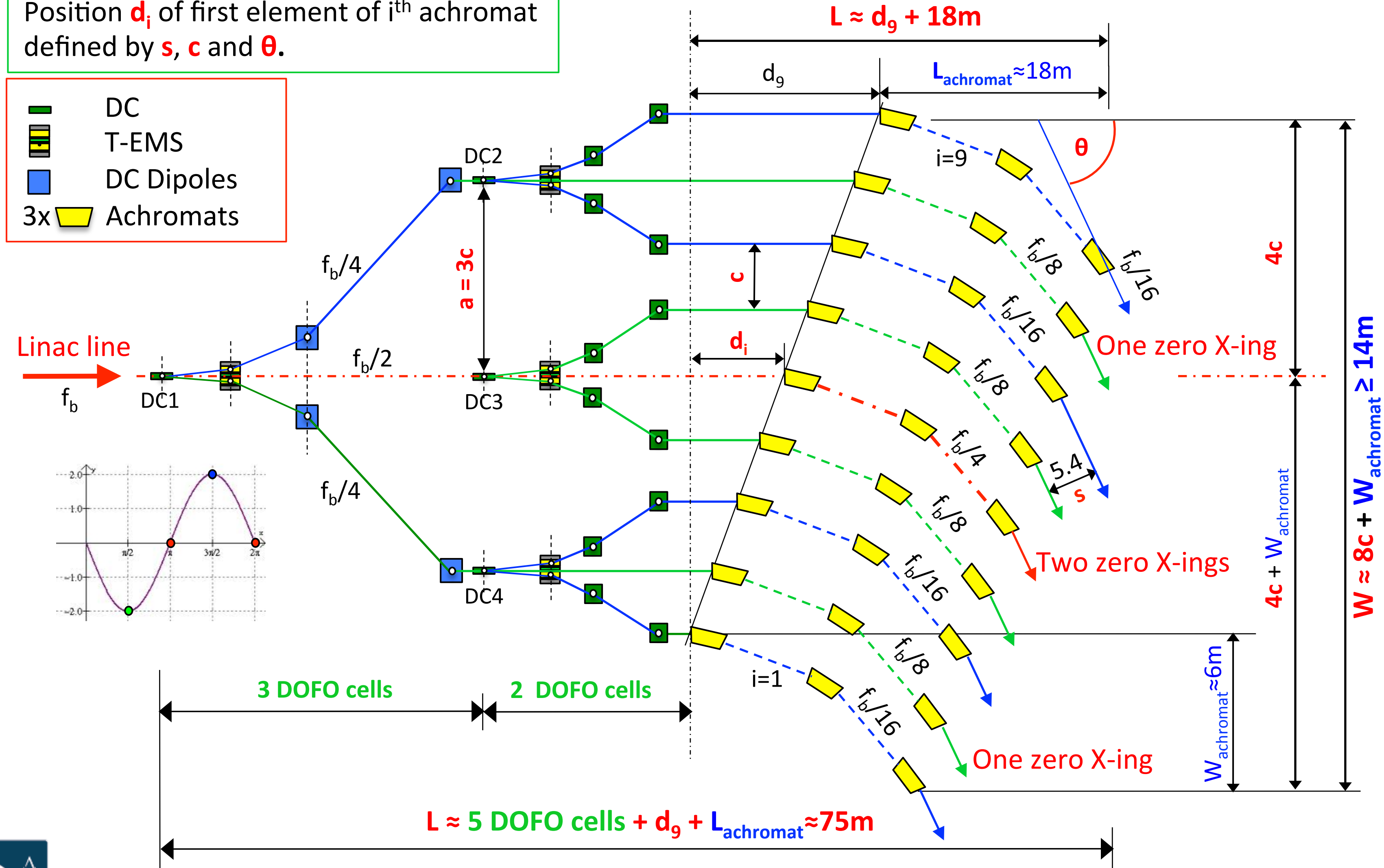
- We need low frequencies for emittance preservation
- Multiple stages can only be done using different frequencies
- We limit the design to two stages
  – We have to assume zero crossing does not compromise beam quality
- One Deflecting Cavity would replace three kickers and Electrostatic septa
  – With a 10 MV kick

An initial 3 beamlines layout



A 9 beamlines layout

Position d_i of first element of i^{th} achromat defined by **s**, **c** and **θ**.



Layout parameterization / 1

Nine beamlines

Three bunch frequencies: $\mathbf{f_b/4}$ (1x), $\mathbf{f_b/8}$ (4x), $\mathbf{f_b/16}$ (4x)

Six lines without RF zero X-ings, **Two** with one, **One** with two

- Total deflection $\boldsymbol{\theta}$ can be optimized to limit **CSR effects** with a proper choice of the position $\mathbf{d_i}$ of the first element of i^{th} achromat and the separation **c** between the nine parallel lines for a desired separation **s** between FELs beam lines.

- Together with the **three-bender Achromat** and the **dog-leg lengths** the **parameters c** and $\mathbf{d_i}$ determine the **spreader footprint.**

Layout parameterization / 2

Position d_i of first element of i^{th} achromat defined by **s**, **c** and **θ**

$$d_i = (i-1)\frac{s - c\cos\theta}{\sin\theta}$$

CDR →

Parameter d_9 vs. c and θ			
FEL separation **s = 5.4m**			
θ [deg]	36	30	25
c [m]	d_9 [m]		
0	9.2	10.8	12.8
1.0	7.8	9.1	**10.6**
1.5	7.1	8.2	9.6
2.0	6.4	7.3	8.5

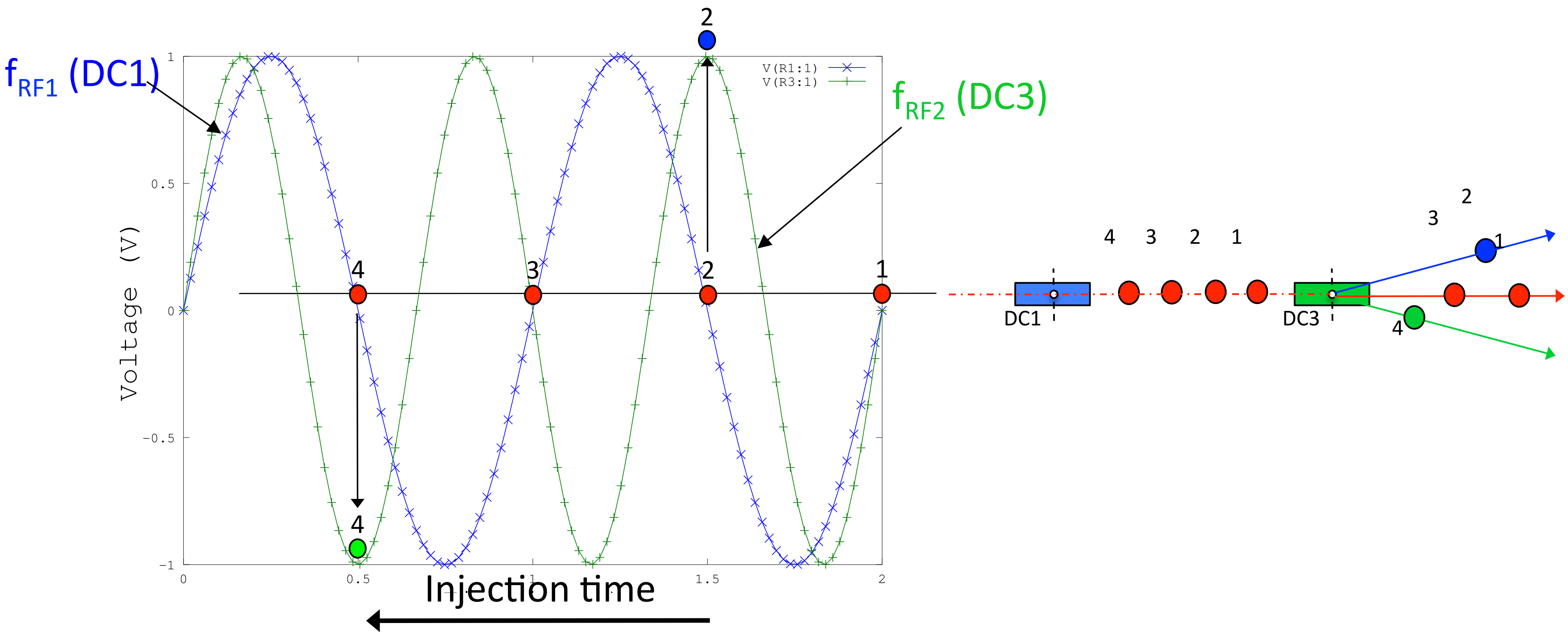
Footprint Comparison for: c=1m, θ=25deg → d_9=10.6m

DC **L ≈ 75m / W ≈ 14m (+4m /-10m** w.r.t. Linac line)

CDR **L = 130m / W =7.5m**

Frequencies at Play

- **This example:** 4 bunches zero X-ing in DC1, 3 beamlines fed by DC3
- f_{RF2} (DC2, DC3, DC4) = 1.5 f_{RF1} (DC1)



Three-way separation - Comments

- Cavities are ≥3m apart: problems with cryo installations?
- Dog leg transitions btw DCs:
  - Quads not shown in layout
  - $\eta_x=0$, not synchronous unless more components
- OPTION - Non-parallel trajectories out of T-EMS:
  - Fewer components
  - Three different achromat deflections
  - Longer longitudinal footprint to preserve lines separation

Three-ways DC separation - Outlook

- **Four DCs for 9 Beamlines** / Present: **9x** (Kicker + ESS) for **Ten lines**
- **Cold CW RF: Bunch Frequency not limited** (Kicker: ~100kHz)
- **Better Deflecting stability**
- **BSY modularity -** Optional Initial layout: **1 DC for 3 beamlines**
- **BSY footprint**
  - **DC Longitudinal 40% more compact: 75m (130m) / 55m shorter**
  - **DC Transverse larger: (4+10)m (7.5m)**.

Current Strawman Design

- Propose to Use f_0 and 1.5x f_0
  - i.e. 325 MHz and 487.5 MHz
    - Good experience with systems at similar frequencies
- Plenty of RF power sources and components available
  - TV broadcast frequencies
- Existing R&D at similar frequencies
  - As presented at this workshop!
  - Some development will still be necessary

Cavities vs. stripline kicker

Pro

- Very high field Stability
- "Unlimited" rep rate
- Easy to find RF sources and components
- Benefit from ongoing R&D in the community

Not-Pro

- Emittance preservation?
- Pulse pattern flexibility?
- Fabrication and maintenance cost
- More extensive installation
- HOMs
- Requires multiple frequencies
- Some R&D required to adapt existing cavity designs

Cavities vs. Stripline kicker

Pro

- Simpler technology
- Simpler installation
- Allows for almost any pattern in any beamline
- Easy to replicate
  - Same design for all beamlines

Not-Pro

- Limited rep rate (few 100kHz)
- Challenging stability (<<10^-4)
- Dedicated R&D required for both pulsers and structures

Open Questions

- Can the beam cope with zero crossings?
  - + Major reduction in n. of beamlines
  - – Emittance growth + reduced FEL performance
- HOMs + dampers?
- Geometry – sizes
- Other creative schemes could allow for more flexibility in the beam patterns

Summary

- Deflecting cavities for the spreader are becoming increasingly appealing
  - The whole project is still in conceptual design
- We plan to continue this study and work with our many collaborators to study the major issues
- Recent great progress in DC technology (as shown at this workshop) make it easier to envision an implementation in NGLS
- Timing, synchronization and RF controls is one of the group's strengths and not expected to be an issue

NGLS
next generation light source

Questions?

BERKELEY LAB

U.S. DEPARTMENT OF ENERGY | Office of Science